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The Role of the Dot in Handwriting Computation: A Cognitive Linguistic Perspective on Arabic Handwriting Recognition

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ABSTRACT

Arabic handwriting has faced several challenges throughout its historical journey. First, its morphological problems were overcome through 'Abu l-'Aswad's endeavors. Then, with the efforts of Nasr bin 'āsim and Yahya bin Ya'mur, the closure of its graphic sign system was addressed fulfilling its linguistic functions. Next, through the reforms of 'Al-farāhīdī its coding was completed. In addition to these achievements that resolved the phonological and semantic issues in developing the graphemes of the handwriting system, Ibn Muqla introduced a new challenge on the aesthetic aspect of the letter. By following strict rules that established the aesthetic proportions of each Arabic letter and its subordinate elements according to each type of font, the dot became a geographical unit of measurement. This approach was endorsed by those who came after him, such as 'Ibn 'Al-Bawwāb and Yāqūt 'al-Musta'simī. However, in the modern era, Arabic handwriting presents us with a new challenge, as it has become an integral part of the electronic, digital, and computer communication structures, and solutions for the automatic recognition of Arabic graphemes. Despite the existing efforts in many laboratories and research institutions, the subject raises problems such as the formation of Arabic letters, their design and construction, the capabilities of automatic recognition, and the need for faster letters readability.

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I. INTRODUCTION

Arabic writing authentically illustrates linguistic sounds through a system of signs organized in multiple levels. Each level aligns with a spoken language aspect, beginning with the phonetic level linked to graphemes, progressing to the lexical level associated with words, and culminating with the syntactic level related to the line.

It is true that writing and speech share the same objective and systematic aspects, as well as systems and structures. They fulfil the basic function of language — communication — and are both subject to scientific research methods. However, there are also fundamental differences between writing and speech, which make writing a distinct form of communication. Consequently, the study of writing encompasses a variety of formal and pragmatic topics, including its systems, structures and textures.

In line with the requirements of the times, contemporary linguists have chosen the field of computer research. This discipline uses computer systems to understand human language and simulate human intelligence (Rashwān & al-Muʿtazz Billāh, 2019, p. 17). It also involves studying linguistic codes and processing them automatically using programs, applications and methods developed in the field of artificial intelligence for dealing with data through investigation, extrapolation, identification, analysis and processing. Writing in its various forms is one of the processes influenced by recognition oriented towards human cognitive stages, with the aim of mastering mental processes to produce, understand, and perceive language (Ḍabʿī, 2022, p. 119).

This presents us with the problem of the extent to which the elements of the calligraphic structure are recognized and understood in order to clarify the intended connotations.

The present research attempts to answer the following questions:

1. What are the existing problems in recognizing Arabic writing?
2. What methodological, linguistic and cognitive solutions can be suggested to overcome these problems?
3. In what ways can the work of calligraphers such as Ibn Muqla and Ibn al-Bawab contribute to establishing standard parameters for Arabic letters that facilitate their computerisation and integration into automated systems for communication purposes?

The main objectives of this study are to:

1. Identify problems related to the Arabic handwriting system, including its technical, aesthetic and cognitive characteristics;
2. Link the aesthetic and mechanical design aspects of Arabic letters according to the mechanisms of visual and cognitive letter recognition;
3. Highlight the importance of Ibn Muqla's approach to letter design when it comes to solving problems relating to the computation of Arabic letters.- propose practical solutions to address issues relating to the automatic recognition of Arabic handwriting.

1.1 Conceptual Framework

Technical and computer research has significantly advanced in terms of tackling the challenges of natural languages, with its focus on adapting to contemporary demands and aligning with developments across various fields. It is assumed that the existing problems in Arabic handwriting will be solved by applying the most effective and appropriate solutions to its calligraphic structure. Interest in studying Arabic calligraphy in terms of its structure, function, aesthetics and grammar goes back more than 14 centuries. Therefore, the current research assumes that finding solutions to the problem of recognition in Arabic handwriting will primarily depend on the characteristics of Arabic handwriting, and the nature of its components. Computer technologies and programs will then be used because they are designed to support these characteristics.

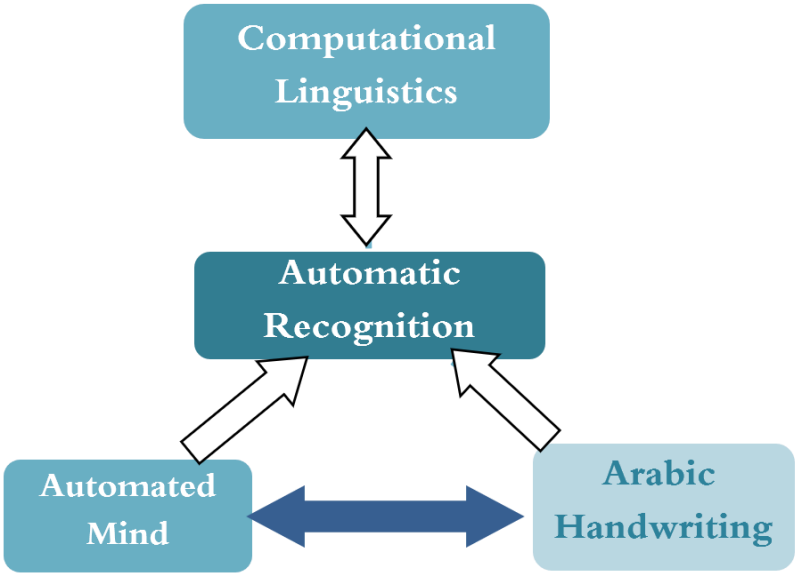


Figure. 1 The status of automatic recognition of Arabic handwriting (designed by the author)

All elements of Arabic handwriting, including all forms of graphemes known as allographs, represent a corpus for studying the subject, since each element has a distinctive connotation and is subject to the substitutional and syntactic relations, as are phonemes. The difference is that graphemes function visually (visually perceived), while phonemes exist acoustically (acoustically perceived).

The present study examines the structure of Arabic handwriting by analyzing the identity of letters and graphic syllables and the connotations they provide to human and machine readers, aided by the ontological and geometric presentation of Arabic letters within a uniquely defined structure of Arabic handwriting.

The research addresses one of the challenges in computer recognition of Arabic handwriting, encompassing its graphical, structural, and functional characteristics. Despite ongoing efforts by individuals and companies worldwide to automate and computerize this process employing various mechanisms and approaches, further development is needed. A comprehensive recognition of all elements of Arabic handwriting (including similar letters and grammatical marks, etc.) has not yet been achieved, highlighting that the architecture of Arabic letters has not been fully comprehended.

II. LITERATURE REVIEW

The linguistic problems addressed by computational linguistics are many, including those related to the subject of automatic recognition of Arabic handwriting. Bahashwan and Abu-Bakar (2015) addressed the issue of automatically recognising handwritten Arabic characters without an internet connection. They concluded by proposing an effective algorithm for this purpose. The derivation of character features was from spatial and curved domains, while the structural features were derived from spatial domains. This feature vector is used to train the classifier on the recognition task; the proposed method revealed a promising result in terms of recognition rate, with an average accuracy rate of 90.3% (Bahashwan & Abu-Bakar, 2015).

Benbakreti et al. (2020) demonstrated the effectiveness of using CNN's offline handwritten Arabic word recognition software, which allows for managing large inputs without a pre-processing or feature extraction phase. It performs these operations by summarizing the image features during the re-entry phase. The study showed a significant improvement in classification time, and the identification rate was 97.96 % (Benbakreti et al., 2020).

Ibn Jallul (2021) dealt with the stages of digitising fonts. The introductory stage involves the automatic identification of Arabic handwriting from

a purely automatic perspective, whether in the direct (offline) or indirect (online) system. This is followed by the segmentation stage, the stage of extracting features, and finally the classification stage, also known as the identification stage.

The author of this study does not claim that it is the first to address the topic of automatic handwriting recognition, as previous studies have already established its relevance. However, the limitations of previous research should be noted.

Firstly, these studies took a purely technical approach to the topic, failing to link it to the nature of the writing system or the cognitive and functional aspects associated with writing as a human phenomenon, as well as a neuro-motor, linguistic, educational and graphological process. These aspects can be utilised during the automated and digital processing of graphic structures, positively affecting the computational side of various font styles.

Secondly, previous studies were limited to intentional sampling in order to identify algorithms that control the automatic identification process. This perpetuates the problem, given that the number of typical Arabic font types may reach 108 (Rougab, 2019). The number of communicative fonts is equal to the number of individuals whose graphological features are distinct. This requires identification solutions that are characterised by the highest levels of validity and reliability for all types of Arabic handwriting, without exception.

Finally, the failure of previous studies to develop comprehensive algorithms for all typographic and handwritten Arabic fonts has created a clear knowledge and computational gap between research findings from computational applied linguistics and technical engineering using logical disciplines such as mathematics. According to the International Applied Linguistics Society, these two research areas are complementary. The current research aims to bridge this gap.

2.1 Definitions

Arabic handwriting is the structure of graphemes represented by phonemes (Bouabdallah, 2007), from which words are formed. Semantic sentences are then constructed from these words, adhering to the spelling, semantic, syntactic, aesthetic, and perceptual rules developed by linguists and calligraphers, which are followed by their successors to this day.

Automatic recognition involves mathematical algorithms and automated processes that simulate human perception, aiming to identify patterns, perceptions, and external stimuli such as sounds, shapes, colors, and Arabic letters. These algorithms help distinguish the unique characteristics of each letter, word, or line from others.

Language computing encompasses processes wherein computers analyze aspects of human language, including word processing, spoken speech, and images (Rashwan et al., 2019).

The dot is the mark made by a pen on paper or another surface, where its length and width are equal, forming a square or rhombus shape.

III. ARABIC HANDWRITING, ITS FUNCTIONS AND LINGUISTIC CHARACTERISTICS

3.1 Functions of handwriting

These functions can be regarded as the specific characteristics of any means of communication, describing handwriting as that which performs the communicative function of spoken language. In addition to functions identified by graphologists and grammatologists, linguists have largely elaborated on handwriting functions including the following (Olivaux, 1991):

3.1.1 Instrumental function

The most important function of calligraphy is the instrumental function, which stabilizes thought or speech, transforms it, and communicates it. With this characteristic, it becomes an indispensable or irreplaceable means or instrument.

3.1.2 Relational function

The method of conversation, expression, and communication is crucial for each individual, and handwriting holds similar significance. The relational function indicates that handwriting must be readable and understandable, accepted by the recipient, and perhaps even liked (Bouabdallah, 2014), as shown in Table 1.

Table 1. The relationship of handwriting to various levels and values (Bouabdallah, 2020)

Level	Nature	Value	Objective
Graphical	Readable	Graphic	Inductive
Semantic	Understandable	Semantic	Clarity of meaning
Linguistic	Acceptable	Linguistic	Communication
Aesthetic	Loved	Aesthetic	Being fun

3.1.3 Personal perception function

The graphic structures differ from person to person; some are very present, seeking meaning, while others attempt to compensate for their shortcomings in handwriting by distorting calligraphic models and giving the calligraphic structure an aesthetic tinge. This creates an aspect of coverage or serves as a mask, resulting in handwriting that carries minimal spontaneity and the true value of what it conveys (Olivaux, 1991).

In order to fulfil these three functions — instrumental, relational and personal perception — it is essential to consider the following elements: the sender and receiver; the calligraphic effect; the criteria adopted for formation; and the mode of communication. These elements define the characteristics of the calligraphy phenomenon, as described in the subsequent sections (Achard, 1988).

3.2 Characteristics of handwriting

During daily dialogue, the two parties, the utterer and the recipient, will have questions and answers between them; these linguistic expressions can be verb or nominal sentences, linguistic marks, phonetic connotations, gestures by hand or face, and so on.

The rhythm of handwriting relates to the slowness and speed of calligraphic production, which influences the control of graphic patterns and units, causing them to vary from person to person.

The presence of the handwritten traceability distinguishes the handwriting process from that of speech as, contrary to what linguists believe, handwriting exhibits notably standardized morphological characteristics. However, speech may exhibit the same characteristics in some circumstances.

The elements of the handwriting structure can be summarized as follows: calligraphic icon, calligraphic unit (grapheme), letter, space and time, whiteness (vacuum), blackness, punctuation, and line (Al Magri, 1991).

All these elements contribute to constructing a formal pattern, which must be considered when designing handwriting elements. The calligraphic icon, which may represent punctuation marks or the stroke of a pen, is important in identifying phrases and, consequently, understanding the overall meaning.

3.3 Arabic handwriting as a topic for computing, artificial intelligence and automated processing

In this context, we do not need to distinguish between the three terms—computing, artificial intelligence, and automated processing—as handwriting (typing or manual) is equally impacted by all three concepts, provided it meets the objective of transforming the linguistic system into one governed by mathematical algorithms, computer processes, and machine cognition, along with all related digital intricacies. Our primary focus here is on the specific criteria of Arabic handwriting, particularly those connected to writing.

3.3.1 Psychological Criteria

Psychological criteria relate to the graphological aspect, which starts from the psychoanalysis of linear elements, to reach the derivation of the specifications of handwriting activity, in addition to considering the mental

connections (motor and cognitive) during the handwriting activity, the most prominent of which are concentration and attention. This control affects handwriting activity through the control of the handwriting tool, the handwriting swiftness, the pressure ratio on the sheet, the perception of graphemes (form and significance), the continuity in writing, and the method of linking the letters.

3.3.2 Technical Criteria

The artistic character of Arabic handwriting and the nature of its geometric forms express aesthetic aspects rarely found in another linear system. This is evidenced by its use in the decoration of mosques and homes. The sensation in Arabic handwriting is not only the consistency or composition of the lines; the angles and extensions help to distribute the lighting and the direction of sight in the painting, so that it becomes a total and inseparable compound (Al-Kurdi, 1982, p. 46). In addition, it is considered an inspiration for many artistic ideas in letter paintings.

3.3.3 Electronic Criteria

Arabic letters are a linear translation of linguistic sounds in graphic form. They are represented as automatically processed images governed by electronic (digital) controls. An image is a group of consecutive dots of different dimensions that represent certain linear shapes forming a physical volume containing light rays or electronic analogies. The dots may also represent a phrase with mathematical numbers (digital image). The image has two spatial variables, (x, z), which measure the degree of light density in the two rays. The following equations (Bollon et al., 1995, p. 8) can be used to represent this:

$$M = H2\text{-}H$$

$$(X, Z) - M (X, Z)$$

$$Y = M (X, Z)$$

Given that H is a real numbers set containing (X) and (Z).

Thus, image (Y) is a continuous two-dimensional function in Y=M (X, Z), so that M = the value of the space intensity at the dot (X, Z).

From the above, handwriting can be considered a physical movement, carrying a linear connotation within a multidimensional space.

3.3.4 Athletic Criteria

Arabic letters are shapes that bear the characteristics of geometric images. They are parts of a circle, a triangle, or a straight line, which led to the emergence of mathematical calligraphers who attempted to establish mathematical rules for Arabic handwriting, relying on mathematical standards such as length, width, and curvature. Undoubtedly, this geometric mathematical dimension of Arabic handwriting has preserved the forms of letters from distortion and various geographical deviations. It resembles meters in Arabic poetry or the laws and proportions governing astronomical phenomena. Additionally, computers can utilize these rules in the automatic identification processing.

3.3.5 Spelling Criteria

Spelling criteria consists of rules dictating the correct drawing of the shapes of linear units (graphemes) in their original positions and locations, as stipulated by linguists and graphologists. The importance of this rule lies in the fact that learning any form of writing, including Arabic handwriting, must first and foremost mind the correct spelling for drawing letters, including the rules of writing the hamza (the letter: a'), the two types of ta', and words in which letters are added or omitted (Baqshish, 2000; Ibrahim, 1998). It is also important to understand what should be connected and what should be separated such as: innama (indeed), inna ma (indeed + relative pronoun: that which), and haithuma' (whenever) and haithuma' (wherever), as well as other matters related to dots and shapes (Wali 1985, p.57).

3.3.6 Morphological Criteria

These criteria relate to all morphological phenomena such as substitution, reasoning, inversion, addition, omission, and various changes in the structure of the word.

3.3.7 Grammatical Criteria

The grammatical criteria are considered one of the most important standards in relation to the word system, as they determine the function of each linear unit and adjust its form at the structural level. According to Tammam (2021, p. 178): 'Arabic grammar comprises a range of general grammatical meanings, which are referred to as sentences and methods, as well as a set of relationships that link private grammatical meanings, such as subjects and objects, and public grammatical meanings, such as general words meanings, until the desired statement is produced.' (Tammam, 2021, p. 178)

Despite this importance, we cannot separate this control from the morphological officer because grammar has diverse meanings from pure morphological structures (the different structures of words), as follows.

Figure. 2 The role of grammar rules in understanding linear units (designed by the author)

3.3.8 Semantic Criteria

Making letters in terms of their drawing, their interdependence, and their consistency with each other has an external value for a semantic work in itself. Once we see the shape of a letter (dāl), we realize that it is a linear symbol for a sound (meaning), as well as punctuation marks, which are considered, and this applies to all elements of the graphical structure.

3.3.9 Cognitive Criteria

By describing the letters as forms available for readability according to the stages shown in

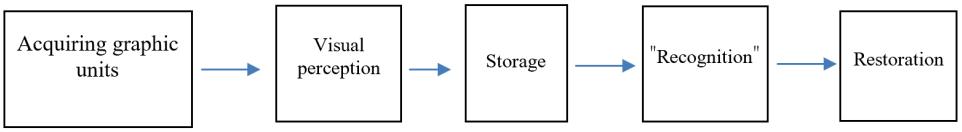


Figure. 3 The cognitive stages of the handwriting process (designed by the author)

3.3.10 Geometric Criteria

Geometric criteria are what this research suggests as the foundation on which the shapes of all letters are designed. Their proportions are determined, which the calligraphers demonstrate as the aesthetic of the letters within the linear plate. Based on those lines, programs and algorithms were developed for most standard computer fonts, such as Traditional Arabic, Arabic Transparent, Simplified Arabic, Tajawal, and Sakkal Majalla.

IV. AUTOMATIC IDENTIFICATION, ITS FORMS AND MECHANISMS

It is clear that all processes in a computer (the electronic mind) are simulations of the human mind, and all concepts related to mental activity can be achieved through mathematical algorithms and logical applications. This requires thoroughly representing those concepts and their related mechanisms because any failure to use these mechanisms cannot be compensated for by algorithms; they are the plan that leads us to our predetermined goals. “Identification” is one of the concepts related to automatic identification; it is a feature used by the human mind during cognitive processes. It is the same concept employed in computing activities. It can even be said that what applies to the human mind’s recognition process is reflected in engineering perceptions and technical applications.

4.1 Formula concept

A formula is defined as a coherent, regular unit of a set of interacting parts. One of its prominent characteristics is that it is not merely the sum of the parts stacked or grouped. Rather, these

parts are interactive, affect each other, and are related to each other.

Thus, a formula possesses characteristics that extend beyond those of the individual parts. The geometric square is a formula but has qualities that do not exist separately in each of its four sides (ʿĪsawī, 1993).

The formula gives the parts their meaning and characteristics because the parts do not have absolute qualities or functions. The length of the straight line varies according to the formula in which the direction of the arrowhead is attached to the end of it; the straight line in (a) appears shorter than in (b), although they are equal.

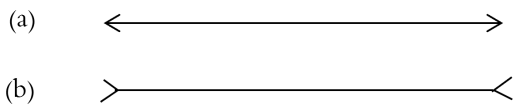


Figure. 4 Deception in the length of the straight line

This is due to the direction of the arrowhead in each. This phenomenon is known as the illusion of the visual senses, so that the shape can become a ground, and the ground can become a shape (ʿĪsawī, 1993) as follows:

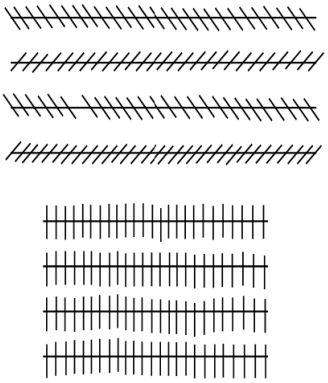


Figure. 5 Deceiving the senses (ʿĪsawī, 1993)

What concerns us in the field of formulas in this research are letters as forms and their relationships with model formulas. These formulas possess spatial characteristics, often represented on paper, a blackboard, or similar surfaces. On the other hand, we consider the relationship between these formulas and the writer's perception, as well as the computer writer's perception of them.

4.2 Linear units

What explains the subjective view in the identification process of these letters is what has already been mentioned: the number of lines corresponds to the number of people. Therefore, we will attempt to examine the typical image of the Arabic letters and monitor the relational interactions among the various linear icons forming the graphical structure and the reflections of known geometric shapes on these graphical units. Then, we can compare the two shapes, the model and the personal:

Table 2. Relationship of the Arabic graphemes to some geometric shapes (typical vision)

Figure	Bookmark	Graphical units bearing the figure
.	Dot	ب، ج، خ، ذ، ز، ض، ظ، غ، ف
..	2 dots	ت، ق، ي، ة
\	Three dots	ث، ش
ا	Vertical Straight	ا، ط، ظ، ك، ل، لـ، م
ب	Part of a rectangle	ب، ت، ث، ف
	Part of a triangle	جـ، حـ، خـ، د، ذ
^		∧ (ثلاث نقط)
		
		ك
	Part of a rectangle	
´	.	ّ(شدّة)
		سـ – شـ
°	Small circle	ة، ف، ق، هـ
	Part of a small circle	عـ، غـ، ي، ء (همزة)
	Arc of a circle	ر، ز، و
	Part of a large circle	خ، ص، ض، غ، ق ل، ن، ي

○	Circle	○
◯	Semi-circle	ص، ض، ط، ظ
||	Two parallel lines	الـ، لـاــ ، طا، ظا
_	Stroke of a pen (before letter)	جميع الحروف عدا (ء)
_	Stroke of a pen (after letter)	جميع الحروف عدا (ا، د، ذ، ر، ز، و، ء)

Table 2 shows that the graphical units consist of more than two types of shapes, such as /al-bā'/, which is made up of a dot and part of a rectangle, and/dād/, which is formed from a dot, half of a circle, and part of a large circle. There is one letter, /'alif/, which consists of a single form that is a straight line. Perhaps for this reason, it makes the first alphabet in order, a transition from the simple to the complex, and it is chosen, geometrically, as a measure for the proportions of the other letters.

From this graphic disclosure, we can assert that our perception of a particular letter is based on its group of parts, which vary from person to person according to their prior experiences. If we asked a group of people to write the letter /'alif/, which, as we have seen, is merely a vertical straight line, we would see various patterns for this letter in terms of length, size, speed of formation, pressure on the paper, positioning in whiteness, and its relationship to the size of other letters. Table 3 shows examples of the graphological performance of the letter "rā'" as observed from some individual graphics formations.

Table 3. Graphological performance of the letter /rā'/

Graphic unit	Some possible cases for the formation of the letter "rā'"			
rā'				
				
				

This graphic diversity is somewhat similar to verbal performance in linguistic research (Jābir, 1998)

From the above, the process of forming graphical units requires several cognitive processes, the most important of which are presented in Fig. 3.

Each of these stages has its importance depending on the need. The stage of acquisition and visual perception is the final registration of graphical units, and the stage of identification and recall is a reflection of what is already in the mind.

4.3 Trends in the interpretation of identification and perception of forms

There is general agreement among most cognitive psychologists that cognitive psychology is the science of forming and managing various types of information that an individual acquires, as well as the processes related to how this information is acquired, retained in memory, and reused. These operations are collectively referred to as cognitive processes.

There have been several main trends in the interpretation of these psychological processes and phenomena, including one that focuses on the individual and another on the environment (Jābir, 1998), along with what is known as the Gestalt School. In the book "The Significance of Image" "for a systematic approach to visual discourses" Bernard Cocula and Claude Perrotet (1986) provide abstracts and compositions of the most important contents of the theoretical heritage of Gestalt regarding visual perception in general and forms and images in particular (Al Magri, 1991, p. 19). They outline a set of laws according to which a group of elements can be perceived as a form:

Law 1: Law of Smallness: The small form stands out separately from larger depths.

Law 2: Law of Simplicity: The simple form is more prominent than the complex form.

Laws 3 and 4: The Laws of Regularity and Reciprocity: This pertains to the orderly and reciprocal division of the elements of a particular form.

Law 5: Law of Difference: This allows the innovatively shown shape to stand out better. These laws focus on distinguishing shapes from depth. Regarding the elements that make up shapes, the authors promote a set of criteria for recognizing certain elements as constitutive elements of a particular shape: namely proximity, similarity, and sequence criterion.

Talking about the whole and the parts, separation and discrimination, shape and depth, stability and its standards requires talking about the problem of perceiving space (already referred to in the elements of the graphical structure), and Gestalt means all the geometric manifestations of things. It mainly relates to elements: location, direction, magnitude, distance, etc. These concepts seem to have a strong relationship with the graphical structure, and they must be considered when algorithmically designing letters.

4.4 Difficulties in recognizing Arabic handwriting

Visual Character Recognition (O.C.R) programs, despite their current effectiveness, face many challenges with respect to Arabic handwriting that all researchers from specialized institutions seek to address. The main difficulties concern the diversity of the shape of letters, size variation, connecting letters, dotting, connecting letters, and diacritics.

These difficulties pose challenges to the validity of the results during identification, whether at the level of graphic signs (letter, syllable, word) or lines (sentence, paragraph). Figs. 6 and 7 present a typical representation of this.

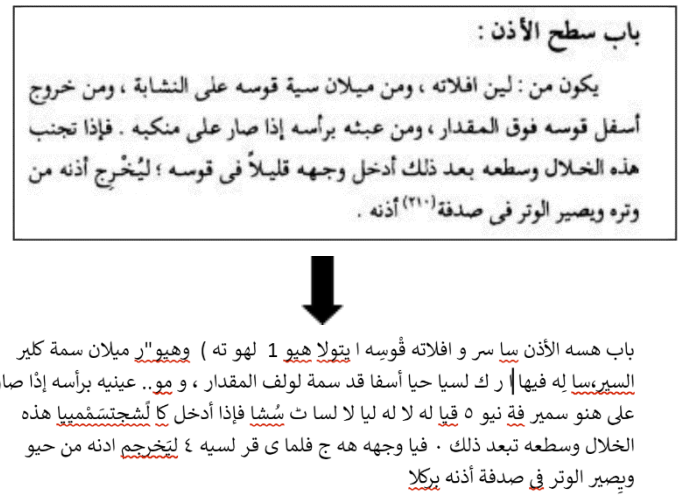


Figure. 6 Search result by identifying the word (taṣdīf)

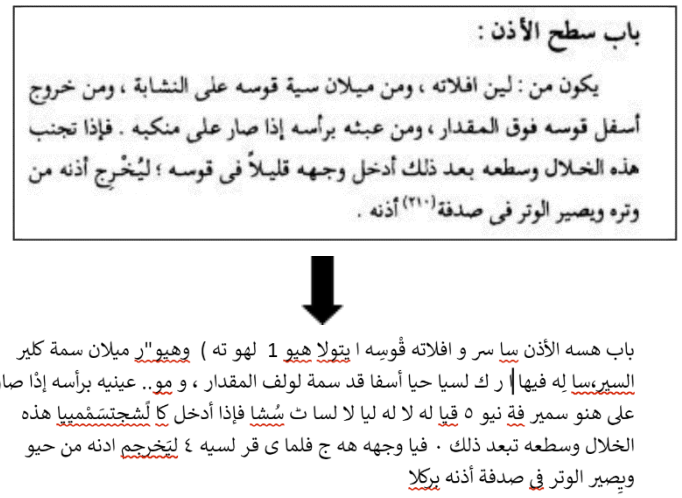


Figure. 7 Search results by identifying a paragraph

This deficiency has led many institutions and specialists to strive to improve the significant recognition rates, but in the researcher's opinion, they remain insufficient (Nassar, 2010). When we compare what computer programs have achieved in identifying the handwritings in other languages , such as Latin, the main reason for the failure with Arabic handwriting is the clear difference between the Latin handwriting systems and the Arabic as well as similar handwriting systems such as Persian and Urdu.

4.5 Cognitive foundations of automatic recognition of the Arabic handwriting

Arabic handwriting incorporates various linguistic features and serves a crucial communicative function, which can be demonstrated through several linguistic theories.

4.5.1 Learning theory for Arabic handwriting

Learning is a psychological and educational process that occurs through an individual's interaction with their environmental experiences, ultimately leading to an increase in knowledge, tendencies, values, and behavioral skills. Theories in this domain comprise proven logical descriptive rules that focus on understanding and interpreting learning behavior from a distinct perspective. The theory of learning encompasses the acquisition of various linear forms of Arabic letters, alongside the rules and regulations required for their distinction and identification. These responses arise from stimuli or incentives that enhance attempts to

recognize and comprehend these forms, enabling individuals to grasp the meanings of the letters and the rules governing their formation according to the following aspects:

- Adherence to linguistic and non-linguistic rules while learning Arabic handwriting.
- Access to a range of linguistic information available through practicing the forms of Arabic letters.
- Development of abstract hypotheses to draw the lines of polymorphic hamza, allowing for the assimilation and formulation of limitless linear forms resembling them while isolating shapes that do not align with their depiction according to human linguistic competence. This competence refers to the implicit understanding possessed by the user of these rules and the performance that represents the application of this competence in its context, responded to by stimuli or incentives. Behavioral theory interprets learning as responses to specific stimuli directed by established rules.

For instance, when executing procedural steps, a child learns Arabic handwriting and utilizes cognitive abilities to grasp the instructions and guiding principles for line units. When the child effectively completes the necessary steps in practice, procedural knowledge is executed automatically or unconsciously without the need for concentrated attention. Higher cognitive abilities facilitate skills such as classification, organization, and comparison of linear units, leveraging memory to gather and analyze information. This leads to a stage of creativity, where imaginative thinking emerges, fueled by acquired hypotheses and predictions based on available information to elucidate phenomena regarding linear units or resolve problems. Subsequently, the child examines and evaluates hypotheses through understanding and application that aligns with a stored image of the presented model, facilitating automatic identification, which aids in forming or generating Arabic letters. The brain captures the data and retains the drawings of Arabic letters, including variations in font size and adjustments such as adding or removing dots. Font size is a common challenge in handwriting development; children often struggle with ensuring letters remain within the appropriate size constraints. Many handwriting issues arise from a lack of readiness to utilize different forms and sizes and coordinate the spacing between letters, which must be meticulously considered for optimal recognition and memorization of spelling rules to enhance handwriting recognition and production. The didactic techniques in handwriting serve as sensory tools, perceptual in nature, based on linear classifications and groupings according to the following:

4.5.2 Classification of linear units

- {'alif, lām}: The /lām/ differs from the /'alif/ only in the part that comes down from the line.

- {bā', tā', thā'}: /bā'/, /tā'/, and /thā'/ differ only in the number of dots.

- {gīm, hā', xā', 'ayn, ğayn}: /gīm/, /hā'/, /xā'/, /'ayn/, and /ğayn/ do not differ, except in the direction of its head on the line.

- {dāl, zāy, fā', qāf} {rā', zāy, nūn}: /rā'/ and /zāy/ differ from /nūn/ only in the completeness of the /nūn/ arc to form a semi-closed circle above the line.

- {Sīn, Shīn, Sād, dād}: /Sīn/,/Shīn/, /Sād/, and /dād/ differ only in the fact that /Sīn/ and /Shīn/ are serrated from /Sād/ and /dād/ and differ in the number of dots between /shīn/ and /dād/.

- {hā'}:It has an elliptical shape.

- {ṯā', ḏā'}:The /ṯā'/ and /ḏā'/ differ only at the dot above the /ḏā'/.

- {kāf}: Addition of italics above /kaf/.

- {yā'}: It has a twisted shape.

{ } represents the void between the linear letters during their separation.

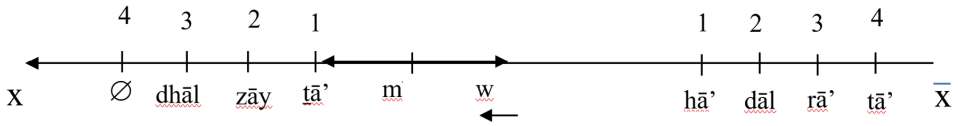
{ - }: The appendix that connects the linear units to connect them, whether in the middle, the beginning or the end.

The following combinations can explain these classifications and comparisons of linear letters:

Gr. (L) = {'alif, bā', tā', thā', gīm, hā', xā', dāl, ḏāl, rā', zāy, sīn, shīn, sād, ḍād, ṯā', dā', 'ayn, ğayn, fā', qāf, kāf, lām, mīm, nūn, hā', wāw, yā', hamza, -}.

The Arabic letters /h/group has an important specialty: if we take a line x m x and a landmark.

(m,w) where (w) is a unit ray parallel to (x m x). It is possible to represent the elements (h) in the dots of this line in the sense that graphically similar n dots offset each linear unit x, and each dot e of the line is offset by a linear unit (y). Therefore, a dot of the line can represent each element of the rest of the group of linear units, and each dot of this line does not need to correspond to an element of that group: for example:



4.5.3 Characteristics of the groups classified among them

Affiliation of linear units in the group

If (bā') is an element of the group{tā, thā}, and we read /bā'/ belongs to {tā, thā}, we say that (bā) belongs to {tā, thā}, and we write (bā') ∈ {tā', ṯā'} and we read /bā'/ belongs to {tā', ṯā'}; if we want to deny the affiliation of (bā') to the group {tā', ṯā'} as it does not have a dot from above the line that is written on it, but from below it, such as (tā') and (ṯā'), we write (bā') ∉ {bā', tā'}, and we read /bā'/ does not belong to the group {tā, thā}.

The empty set { }

It is the designation of a distinctive group, especially the space between the linear units in a state in which they are installed with each other, such as: /bāb/:

The (bā') sticks to the /'alif/, but the second /bā'/ is not associated with the /'alif/ because the /'alif/ is a linear unit that cannot be connected to anything beyond it

Containing linear units in a group

We note from the group {sīn, shīn, ḍād, ṣād} that there are two graphs {sād, ḍād} that resemble the two forms of the graphs in the group {ẓā', ṯā'}. They do not differ except in the shell. We can combine them into a group of units and thus say that the group {ṯā', ẓā'} is contained in the group {sīn, šīn, dād, ṣād} or that the group {sīn, šīn, ḍād, ṣād} is contained in the group {ṯā', ẓā'} and the symbol used is Ì to indicate this relationship.

Thus, it is written as follows:

{sīn, šīn, ḍād, ṣād} Ì {ṯā', ẓā'} or {ṯā', ẓā'} Ì {sīn, šīn, ḍād, ṣād}

We can also deny this inclusion with other groups: for example, we say that group {'alif} is not contained in group {rā', zāy, nūn}, and we write {'alif} Ë {rā', zāy, nūn} or rā', zāy, nūn} Ë {'alif}.

Intersection of linear units in groups

Let the groups be the following: {bā', tā', thā'}, {gīm, hā', xā'}, {'ayn, ğayn},{dāl, ḏāl, fā', qāf}, {rā', zay, nūn},{ṯā', ḍā', yā'}, containing linear units that bear one or more dots in their drawing: that is, they are characterized by a common characteristic among them, from which we write {bā', tā', thā'} Ç {gīm, hā', xā'}, {'ayn, ğayn}, Ç {dāl, ḏāl}, {fā', qāf} Ç {rā', zāy, nūn} Ç {tā', ẓā'} Ç {yā'} = {bā', tā', thā', gīm, xā', ğayn, ḏāl, fā', qā'f, zāy, nūn, ẓā', yā'}. Using Venndiagrams, this intersection is represented in Fig. 8

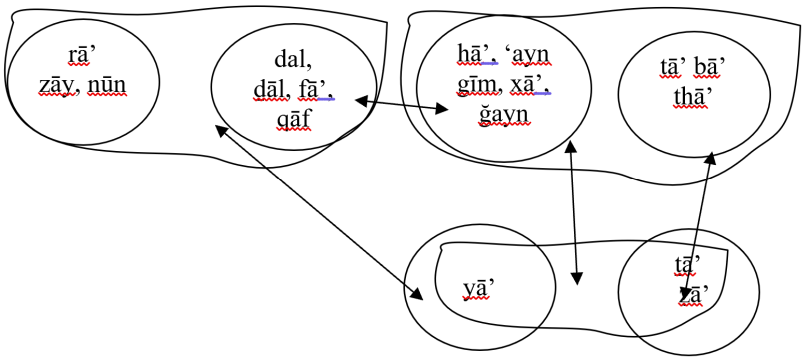


Figure. 8 Intersection diagram between linear units

V. THE DOT, ITS CONCEPT AND ITS ROLE IN THE COMPUTERIZATION OF ARABIC HANDWRITING

5.1. Functions of the dot

Despite the limited dimensions of the dot and the simplicity of its formation, it has many functions, which we briefly mention below:

5.1.1 Syntactic function

Abu Al-Aswad used it to denote the syntactic movements. He addressed his writer: "Take the Quran and a dye that contradicts the color of the ink. If I open my lips, drop one above the letter, and if I join it, make the dot next to the letter, and if you break (Kasra) it, make the dot at the bottom of it" (Ibn Al-Anbari, 1971, p. 41). The dot thus became a grammatical unit (morpheme) to avoid the error and the defect and disorder in the synthetic level of the language that the non Arabs produce.

5.1.2 Discriminatory function

This function is credited to Nasr bin Asim and Yahya bin Yaamur, as it became a phonetic unit and a tool for interrogating letters to distinguish some letters from others (similarities and isotopes). Thus, the dot became involved in structuring half of the number of letters in Arabic handwriting: namely, bā', tā', thā', gīm, xā', dāl, zāy, šīn, ḍād, ẓā', ğayn, fā', qāf, kāf, nūn.

5.1.3 Semantic function

The dot is a punctuation mark that is used (like the period) to signify the end of phrases and sentences, as well as the relationships between structures and their branches.

5.1.4 Educational function

The dot plays several pedagogical roles, as "the child learns in his early stages of school to draw geometric lines represented in straight, oblique and broken dots... before he learns to write." (Al Qasim, 2015, p. 23).

5.1.5 Aesthetic function

The dot is one of the graphic elements used by the calligrapher to balance the ratios of whiteness and blackness in the linear painting, and it is primarily utilized in the Diwani Glee line, which aims to fill in the gaps with relatively small dots that match the size of the dots of the letters. In addition, the dot is one of the approved beginnings at the beginning of the formation of some letters, as stipulated by Ibn-Muqla (1994, p. 123) in his letter: "as for the beginning of the dot, it is of nine forms: alif, bā', dāl, rā', sīn, lām, nūn, ain, hā'."

5.1.6 The geometric function

The importance of the dot lies in the fact that some mathematical calligraphers consider it as a measure of all letters and adjust all their geometric descriptions. Therefore, it is the basic unit for measuring the geometric dimensions of letters, and all graphemes, including spaces (both white and black) (see Fig. 8). Thus, it is considered a geometric criterion for the computerization of letters because of its close correlation to the shape of the letter and its ability to form mathematical and logical equations. These equations can

accommodate all standard Arabic letters in the first stage, followed by their applications to handwriting. Handwriting is only a graphical representation of model letters.

5.2 Ibn Muqla's geometric rules for drawing letters

Ibn muqla had a wide knowledge of geometry, which helped him to develop the calligraphy. The beauty of his fonts was admired in history and literature books. After the Kufic font use in writing the Koran was common, Ibn Muqla introduced the artistic Naskh font, which was praised for its beauty, ease of writing, and clarity. The Kufic font is used only to write the names of the Suras in the Koran. Ibn Muqla, following the example of Ibn Al-Bawwab, completed and perfected the rules of the Naskh font, inventing many of the pens (fonts) on the principles of geometric drawings. He established the font criteria by which a percentage of the interval is set. If it exceeded that ratio, it would be ugly, and if it fell short of that ratio, it would be dull.

Ibn Muqla attributed all letters to the Alif, which he used as a basic measure. Then, he drew a circle around it and placed the rest of the letters in relation to the Alif circle.

5.3 The standard dot for Arabic handwriting

Form—any form—would not exist "were it not for its mother, the dot. The line is the son of the dot, and the line is the father of form. Form is a space open to experimentation and accumulated visual experience, to the extent that we see today in the digital light signals that we transmit electronically" (Abu ʿArab, M., 2023).

Therefore, Ibn Muqla begins by placing a small dot inside the circle to draw the Alif. The standard Alif is a straight line consisting of specific dots placed on top of a peak. The number of dots varies according to the script type – for example, Naskh or Roqa'a – ranging from five to seven, with the height of the circle equaling that of the Alif. The Alif and the circle are reference geometric shapes; Alif is the diameter, and all the letters are built on this diameter. For example, /rā'/ occupies a space equivalent to a quarter of the circle and /Bā'/ is the length of the horizontal diameter of the circle. Furthermore, Ibn Muqla explains that a quarter of the circle consists of six dots. To complete the circle, thirty-two dots must be placed. This simple method establishes the rules of the line, which affords the calligrapher the freedom to innovate and create the forms of the letters, limited only by the proportion of the surfaces. For example, the size of the shape /rā'/ will be constant, and regardless of how often the proportion of a quarter of the circle's circumference is repeated, each letter is a standard form containing dozens of internal sounds, leaving ample oportunity for calligraphers to design and innovate.

Ibn Muqla gave names to some movements within the letters, such as montaseb (stretched), munkab (bended), and mukawwas (arched), which helped him to describe them and the relationships between them. He explained that if another letter is added to some letters, they can generate a third letter, and that is the basis for the formation of the circle in the letters /hā'/, /fā'/, /yā'/, /nūn/, /'ayn/. The semi-circle is manifested in the formation of /sīn/, /sād/, the quarter of the circle in /rā'/, /wāw/, the triangle in /dāl/, /lām/, and the square in /mīm/, and it is measured on all other letters according to the geometric shape that fits the group of letters of the semi-circle, the quarter of the circle, the square of the circle, or the triangle of the circle (Al-Masʿūd, 1981). This can be presented geometrically as follows:

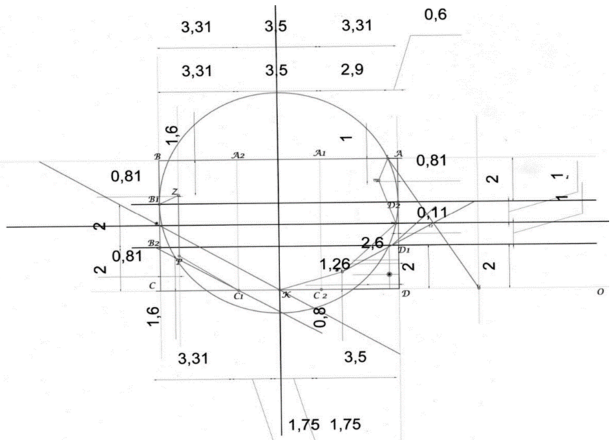


Figure. 9 Standard dimensions of the geometry of the letter (rā')

Through Ibn Muqla's thinking on systematizing the forms of letters, several key principles emerge. First, he began with geometric statements in the development of letter scales and the aesthetic proportions of each linear sign (grapheme). Second, he conceived all Arabic letters as units in an integrated and indivisible system. Finally, he emphasized the importance of engineering and mathematical reasoning in examining natural, industrial, and other forms and perceptions. This remains relevant today by integrating heritage concepts and theories to address character computing and automatic processing issues.

In addition, the concept of the dot as a unit of measurement in Ibn Muqla's work is considered similar to the consonants and vowels of Khalil bin Ahmed Al-Farahidi, or as (0 / 1) in modern algorithms. This demonstrates the effectiveness of the mathematical equations derived from the geometry of Arabic handwriting.

VI. CONCLUSION

Computing and automated processing play an active role in addressing the challenges posed by the Arabic handwriting system, which has unique technical and aesthetic characteristics. The efforts made in the field of computerizing Arabic handwriting and its automatic processing by individuals and contemporary electronic software companies largely replicate the initiatives undertaken in the computerization of Latin handwriting. These efforts, though, appear insufficient.

To understand why these efforts fall short, it is necessary to consider the interrelationship between the technical-aesthetic and the geometric-automatic aspects of Arabic letters. These aspects are influenced by linguistic controls derived from the structure and system of the Arabic language itself, as well as the mechanisms of visual and cognitive letters recognition, which are governed by form recognition standards.

Building on this perspective, the study highlighted the importance of leveraging the aesthetic, artistic, and geometric heritage reflected in the approach of Ibn Muqla and those who followed him in the Arabic letters design to address the challenges of recognizing Arabic handwriting.

Therefore, any proposed solutions to the challenges of recognizing Arabic handwriting must consider all the structural elements of the graphic system, the simplest of which is the dot. This represents a standard, geometric, and cognitive unit. If computer engineers and linguists combine their efforts, they can create mathematical algorithms capable of providing more reliable and valid results for all Arabic handwriting, from typography to handwriting.

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